THE EFFECT OF COMPLEX INFORMATION PROCESSING TECHNIQUES APPLIED TO SHORT TERM MEMORY OF MILITARY OFFICERS

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THESIS

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by

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September 1975

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Unclassified
SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) The Effect of Complex Information Processing Techniques Applied to Short Term Memory of Military Officers		5. TYPE OF REPORT & PERIOD COVERED Master's Thesis; September 1975
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Kenneth Cameron Kodalen		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Postgraduate School Monterey, California 93940		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Postgraduate School Monterey, California 93940		12. REPORT DATE September 1975
		13. NUMBER OF PAGES
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) Naval Postgraduate School Monterey, California 93940		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Human information processing

Short term memory

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

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(Page 1) S/N 0102-014-6601 |

Unclassified
SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

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These results supported the previous findings of Van Gigch who initially approached the problem.

The Effect of Complex Information Processing Techniques
Applied to
Short Term Memory of Military Officers

by

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Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN OPERATIONS RESEARCH

from the

NAVAL POSTGRADUATE SCHOOL
September 1975

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I. PROBLEM

A. INFORMATION THEORY AND ITS APPLICATION TO SHORT TERM MEMORY

It is convenient to treat the complete human information processing system in three stages by which sensory information is processed, stored and used to determine skilled motor activity. Crossman [1964] defined the three stages as analysis of sensory input data (the receptor-system) the organization of action in relation to current objectives (the central processes), and carrying out the required actions (the effector system).

Short term memory is fed by stimuli through the receptor system and is essential to human functioning. Fitts and Posner [1967] defined short term memory as a system which loses information rapidly (60 seconds) in the absence of sustained attention. It is a prerequisite for a longer term store. The terms used to characterize the short term memory differ widely among researchers. Some of the terms used are primary memory, immediate memory and temporal store. The capacity of the short term memory is referred to as a limit or span. Miller [1956] stated that the span or limit of immediate memory imposed severe limitations on the maximum amount of information received, processed and remembered. In addition to the span, Fitts and Posner [1967] concluded that the type as well as the amount of material affected the temporary store. Crossman [1964] estimated as a

result of experimentation that the maximum capacity of this temporary store was 26.6 bits of information. Miller [1956] proposed that the capacity of this temporary store could be increased by efficient grouping called chunking. Norman [1969] referred to this chunking process as recoding. He proposed that the operator recoded the input into another code that essentially contained fewer chunks but with more bits of information per chunk. Sperling [1960] added that rehearsal also increased this temporary store as the material was also remembered in auditory form when it was originally presented in visual form. Norman [1969] noted that the immediate effects of attention also increased the memory store but that its remote effects were too incalculable to be recorded.

Sheridan [1974] realized this memory limitation and asked the following question:

> "Is there a single measure of capacity that applies in some way to all tasks or to classes of tasks, or must the nature of the limitation of performance be determined experimentally for every possible task?"

Sheridan stated that at one time there was hope that information theory would provide the single valid measure for task capacity. He proposed that because the complex information processing steps required for a simple transmission and the possibility that the brain was dual-channeled, a simple, all-inclusive measure was unlikely. Although Welford [1971] and Broadbent [1958] refuted the dual-channel theory and postulated a single central channel with limited capacity, there was still no successful attempt to specify and quantify the different integrative levels or levels of difficulty for a complex task.

B. BACKGROUND OF CHOICE (DISJUNCTIVE) REACTION TIME

Fitts and Posner [1967] defined choice reaction time (RT) as the time elapsed between the onset of the stimulus and the onset of the response. They referenced the work of the Dutch psysiologist, Donders, who made the earliest attempt to deal with this choice RT. His work was later extended by Merkel in 1885, who discovered a logarithmic increase in the reaction time as the number of stimuli and responses increased. Hick [1952] replicated Merkel's experiment and found that the rate of gain of information in that task was a constant. Hilgendorf [1966] stated that since this classical experiment, many later studies such as Bricker[1955] confirmed the direct relationship between RT and uncertainty. Hilgendorf [1966] also reported that RT varied directly with information content with no tendency to deviate from a straight line at high levels for choices of alternatives. His experiment regarded the relationship between information input and response times and used visually presented, discrete symbols of up to 1000 alternatives (9.96 bits) and a key pressing response.

Fitts and Posner [1967] found that there appeared to be a maximum or upper limit to times observed in choice RT experiments. Tasks which have steep slopes (low compatibility) as shown in Figure 1 and high information showed a departure from linearity at the upper end of the curve where the predicted RT tended to exceed the maximum limit. In tasks with a relatively shallow slope, also shown in Figure 1, the relationship continued to be linear out to the highest amounts of information

used, since the predicted value did not exceed the maximum limit. Welford [1971] pointed out that this slope depended to a considerable extent on the relationship between signals and corresponding responses. He proposed that the flattening of the slope relating RT to degree of choice was associated with the increased familiarity or compatibility of the relation between the signal and the response. The flattening of the slope represented a true raising of the rate of information transfer for higher degrees of choice. Gagne and Fleishman [1959] also pointed out that the speed of motor reaction which directly affected RT varied with the particular sense organ receiving the stimulus. They also mentioned that motivation and general muscular tension must be considered.

Fitts and Posner [1967] reported that since information was a logarithmic function of the number of alternatives, a straight line related information and RT and that the reciprocal of this slope $[(X_2 - X_1)/(Y_2 - Y_1)]$ presented the rate of information transmission measured in the units bits/second, where the number of bits (the independent variable) was plotted on the horizontal axis, and RT (the dependent variable) was plotted on the vertical axis as shown in Figure 1. Hick [1952] mentioned an alternative procedure for measuring the processing rate. This procedure was that the total RT to complete the task was divided by the number of bits in the task. The experimentor referred to this technique as the one bit (X_1/Y_1) method and the two bit (X_2/Y_2) method in the present experiment.

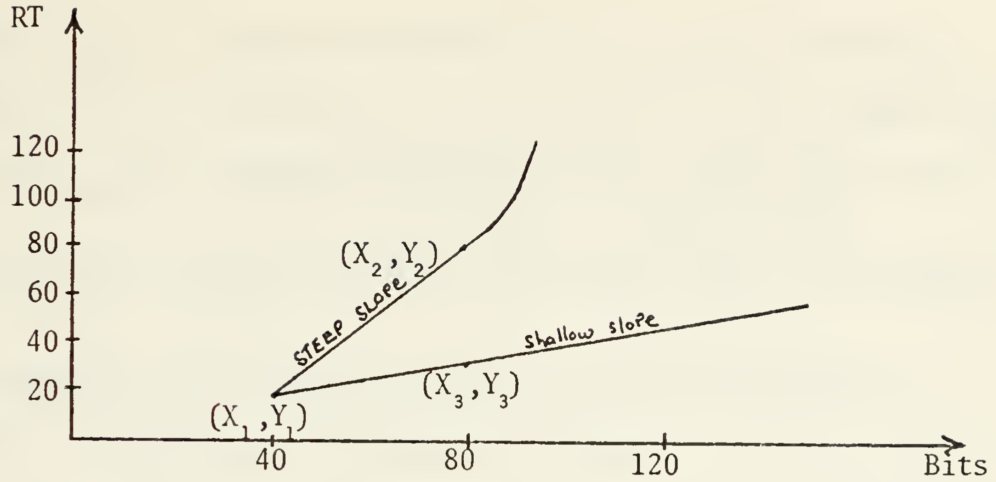

FIGURE 1: Conceptual Model for the Information Processing Rate Procedure

Quastler [1955] concluded that RT was in fact an important measure of human information processing and behavior. For this reason RT was selected as a variable in this experiment.

C. THEORY OF SIMPLE INFORMATION PROCESSING

In the case of simple activity, the amount of information transmitted by the human communication system can be calculated on the basis of a model postulated by Shannon and Weaver [1949]. This model assumed the following:

1. the number of stimuli and responses governing the activity under consideration was limited ;
2. the number of times each response occurs to each stimulus can be obtained;
3. the probabilities governing these events are known and are not changing.

Thus, in such cases the amount of information as described by Nadler [1963] is shown by the Venn diagram in Figure 2 and can be defined in the following manner:

H(X) is the information in the source

H(Y) is the information at the output

$H(X,Y)$ is the total information in X and Y together

$H_x(Y)$ is the information present only in the output (noise)

$H_y(X)$ is the information only at the source, but lost in transmission to the output (equivocation)

$T(X,Y)$ is the information transmitted from the source to the output.

The computational formulas are defined as follows:

$H(X) = -\Sigma p_j \log p_j$; p_j must be known

$H(Y) = -\Sigma p_i \log p_i$; p_i must be known

$H(X,Y) = -\Sigma p_{ij} \log p_{ij}$

$T(X,Y) = H(X) + H(Y) - H(X,Y)$

$H_y(X) = H(X) - T(X,Y)$

$H_x(Y) = H(Y) - T(X,Y)$

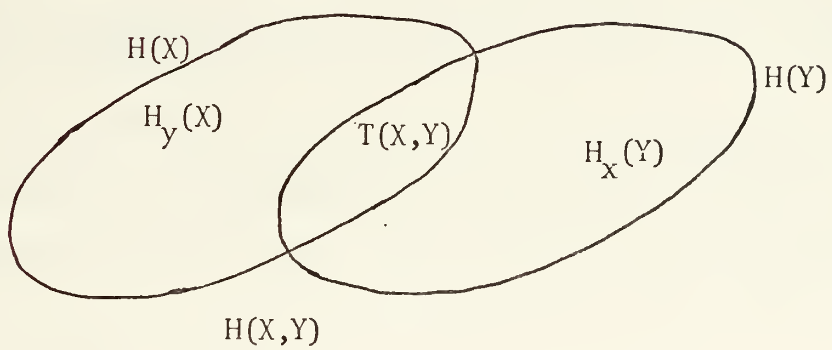

FIGURE 2: Venn Diagram of Information Relations

D. THEORY OF COMPLEX INFORMATION PROCESSING

Krulee [1954] suggested that the complexity of a given piece of equipment was directly related to the amount of information being transmitted by that equipment and that human reaction time (RT) increased with the amount of information to be processed. He also suggested that many tasks can be

simplified if one can be prepared for what is to come (preparatory set) and referred to this as utilization of anticipatory information. To anticipate, a rule must be stored and the correct position in a sequence must be retained in order to apply the rule correctly. Krulee also proposed that if the storage and interpretive problem became complex enough, the operator would probably find it simpler to ignore the anticipatory information and to treat the sequence as essentially random. The conditions as assumed previously by Shannon and Weaver [1949] were no longer valid for this situation because of the following three reasons:

1. the S-O-R correspondence of each task cannot be traced and documented;
2. the activities may not be repeated in the same sequence;
3. the marginal probabilities of inputs and outputs cannot be ascertained.

Therefore, another model must be used to calculate the entropy and the amount of information transmitted in the performance of complex activities and such a model was proposed by Van Gigch [1970].

Van Gigch [1970] stated that the mental content of a task was measured in terms of the total amount of information of all mental therbligs in that task. Van Gigch defined a mental therblig as the basic function involved in completing a given mental task that can be subjected to analysis. Once the mental therbligs required in the task and their corresponding level of integration were identified, the amount of information processed for each therblig can be calculated in terms of the entropy

measures $H^{(1)}$, $H^{(2)}$, $H^{(3)}$, and $H^{(4)}$. The level of integration of the integrative activity expresses the complexity of the information and mental processes involved in the performance of a task. The first level of integration is referred to as $H^{(1)}$, the second level as $H^{(2)}$, the third level as $H^{(3)}$, and the fourth level as $H^{(4)}$. Van Gigch [1970] pointed out that military operations usually involved repeated sequences and therefore the total amount of information per cycle, or for one repetition of the sequence could be obtained.

E. THE PRESENT PURPOSE

Long and Fishburne [1973] reported that the Naval Aerospace Medical Research Laboratory (NAMRL) was employing the RATER in a number of research projects. No work was reported to date investigating the information capacity of the different delay modes in the self-pace configuration. The RATER is presently employed for the assessment of subject's speed/accuracy on basic perceptual-psychomotor and short term memory tasks. The results of this experiment were to present a normative record of performance in this particular task configuration for the population of students at the Naval Postgraduate School. The results will also provide a base-line for later comparative research.

Van Gigch [1970] in his paper recognized the fact that as the mental complex task became more difficult, then more information should be processed. He was unable to experimentally arrive at the proper weighting and arbitrarily assigned the

values bit, dubit (two bits), tribit (three bits) and quabit (four bits), etc. to the different levels of integration for any particular complex task.

Finally, the ultimate objectives of this experiment were threefold:

1. Determine and validate the predictions of the regression equations obtained from fifteen subjects using the slope method, one bit method, and two bit method. Compare these predictions using the processing rates obtained from five additional subjects with their actual performance times on the RATER.

2. Test the three different methods for measuring information processing rate at delay 0 with the actual performance times at delay 0.

3. Determine the amount of information processed at each level and the respective weighting factors for comparison with Van Gigch's estimates.

Before this experiment was conducted, the experimentor conducted a trial experiment (pilot study) which was useful for validating verbal instructions, and ensuring that all the equipment worked properly. During this pilot study, the conditions of the experiment were adjusted so that the task was neither too difficult, nor too easy. It also enabled the experimentor to master the routine of the experiment in order that the results of the experiment proper would be more meaningful and valid.

The purpose for conducting this study should be clear as the emphasis on newer engineering disciplines, according to

Meister [1971], is switching to Human Factors. Recent military projects such as the Navy Light Airborne Multipurpose System program (LAMPS MK III) have applied information theory for the allocation of instrument space on the panel displays.

If the exact amount of information presented in a complex task is known and the maximum information processing rate of the operator is determined, then the Human Factors engineer can determine at which point the operator will be overloaded. The experimentor feels that the use of information theory in these types of applications could noticeable reduce accident rates.

Information processing and information transfer rate research has been and continues to be of interest to the Navy and the Office of Naval Research [Talcott, 1975].

II. METHOD

A. DESIGN

The data from the present experiment was analyzed by a general-purpose statistical package referred to as SNAP/IEDA which performed many of the classical statistical techniques such as stepwise linear regression and correlation analysis. This statistical package was obtained from Princeton University and is presently used on the IBM-360 computer located at the W. R. Church Computer Center, Naval Postgraduate School.

The first four levels of integration were defined so as to equate to the corresponding four delay modes of the miniaturized response analysis tester (RATER) to reflect the increasing complexity of the task.

First Level of Integration	= $H^{(1)}$	= Delay 0 (respond to presented stimulus)
Second Level of Integration	= $H^{(2)}$	= Delay 1 (respond to stimulus presented one back)
Third Level of Integration	= $H^{(3)}$	= Delay 2 (respond to stimulus presented two back)
Fourth Level of Integration	= $H^{(4)}$	= Delay 3 (respond to stimulus presented three back)

The mental therblig, recognition, was defined at $H^{(1)}$ to mean the immediate response to the identification of a known symbol. The mental therblig, ordering, was defined at $H^{(2)}$, $H^{(3)}$, and $H^{(4)}$ and combined selective source entropy with order source entropy. That is, which of the four symbols, a plus

sign (+), a diamond (◊), a triangle (Δ) and a circle (O), in the RATER task must be selected and retained in the proper order (ordered recall). This ordered recall occurred at $H^{(2)}$, $H^{(3)}$ and $H^{(4)}$ prior to response.

Each of the initial fifteen subjects was assigned a different testing sequence for the RATER as listed in Table I. Then, five additional subjects were randomly selected and tested by assigning each additional subject to a previously selected delay series. This was done for validation of the regression equations and the information processing rate methods. The regression equation and the information processing rate method which yielded the highest correlation with the actual RT were selected for future predictive purposes on the RATER task.

	Subjects \ Delay	Delay 0	Delay 1	Delay 2	Delay 3
	1	1	2	3	4
	2	4	1	2	3
	3	3	4	1	2
	4	2	4	3	1
	5	2	3	1	4
	6	1	2	4	3
	7	1	4	2	3
	8	4	3	1	2
	9	3	1	4	2
	10	4	3	2	1
	11	2	1	3	4
	12	3	2	4	1
	13	1	3	4	2
	14	2	3	4	1
	15	3	1	2	4
Validation	1	1	2	3	4
	2	4	1	2	3
	3	3	4	1	2
	4	2	4	3	1
	5	2	3	1	4

TABLE I: RATER Delay Series Assignment Testing Sequence

The dependent variable for the experiment was reaction time (RT) and defined as the time interval between the onset of the stimulus and completion of the response measured in seconds on a synchronous electric clock.

A choice RT was selected as it determined the amount of information processed and required no previous training for the subjects [Fitts and Posner, 1967].

B. SUBJECTS

The subjects for the experiment were twenty (20) randomly selected male students from the Naval Postgraduate School. Subjects ranged in age from twenty-four to thirty-five years with no known mental or physical disorders. All subjects were alert and were eager to participate in the experiment. No incentives or gratuities were paid the subjects.

C. STIMULI AND APPARATUS

A solid state intercom, Fannon, FI-3 master was used for two-way communications between the experimentor and the subject located in the chamber.

1. Information Processing Rate Device

This device enabled the experimentor to obtain the information processing rates for each subject using the slope method, one bit method and the two bit method.

A stimulus presenting mechanism as shown in Figure 3 was connected to a key control to which the subject responded by pressing a key as shown in Figure 4. A synchronous electric clock measured the time interval to within a thousandth of a

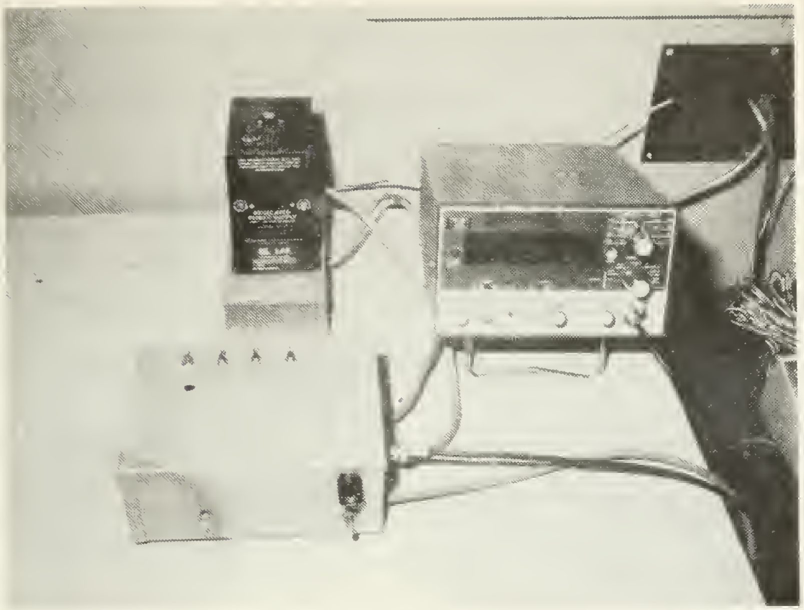

FIGURE 3: Setup of the Independent Information Processing Rate Control Unit with Power Unit and Electronic Timer Outside the Isolation Booth

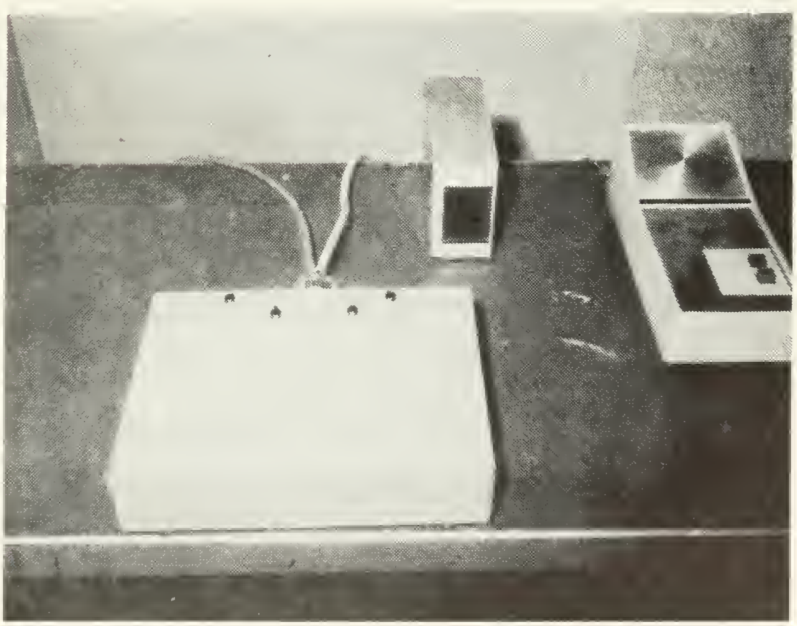

FIGURE 4: The Information Processing Rate Response Panel with Display Unit and Inter-Communication Box

second accuracy between the onset of the stimulus and the completion of the response.

The stimuli used with this device were the equally likely display of the digits two and three for one bit of information and the equally likely display of the digits one, two, three, and four for two bits of information. The subject would depress the button corresponding to the input number stimulus. The stimuli presentation rate was manually controlled by the experimentor in order that no temporal uncertainty would exist. The subject was instructed to respond as quickly as possible to the correct response.

2. Miniaturized Response Analysis Tester (RATER)

The specific complex task used for performance prediction was the Response Analysis Tester (RATER), Model 3. The device, built by General Dynamics Convair Division, is a highly sophisticated psychomotor-testing instrument designed to provide sensitive, reliable measurement of response speed, accuracy and short term memory which incorporated four delay modes. This device is shown in Figure 5. It consisted of a small subject console, containing a display window and four response buttons in a 2 x 2 arrangement requiring a one to one response from the stimulus. The subject's console is shown in Figure 6. The basic task required the subject to press the correct response button for each of four symbols. Symbols were selected over colors as a result of Marsden's [1975] thesis which showed no significant difference between the colors and symbols.

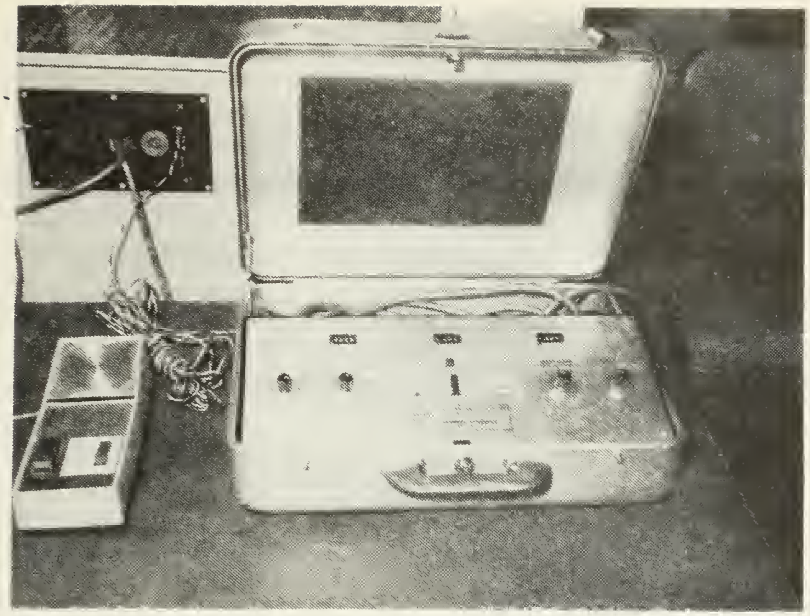

FIGURE 5: Setup of the RATER Control Unit with Inter-Communication Box Outside the Isolation Booth

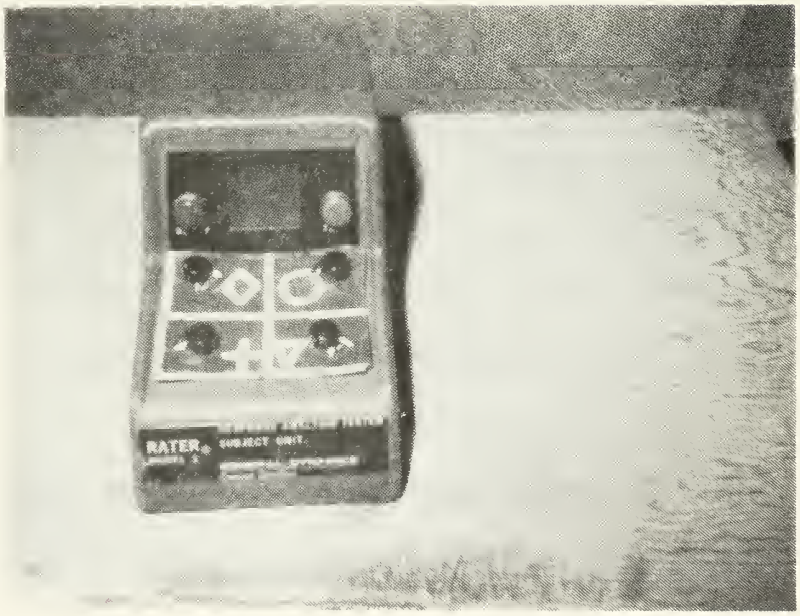

FIGURE 6: The RATER Display Unit with Response Card in Place

The symbols were automatically displayed in a continuous random sequence in the viewing window of the RATER after a correct response was made. A card indicating the correct response buttons was placed under the response button panel and remained in place throughout the experiment.

The symbols were colored white and presented against a dark background.

D. PROCEDURE

The experiment was conducted in the Man-Machine Systems Design Laboratory at the Naval Postgraduate School in an environmental chamber, where outside noise and incidental lighting were controlled. Subjects were briefed on the equipment to be employed and to a degree on what was meant by information processing. The experimentor's purpose was to alleviate anxiety the subject may have and to induce a vested interest in the problem.

The conditions as set forth by Schroder [1967] for successful performance in most complex reactive task environments are listed below and assumed to hold for this experiment.

1. sufficient performance skills and knowledge
2. near optimal level of interest or motivation
3. capacity to engage in complex information processing.

The symbolic condition was used which meant that subjects had to use the symbol shape to translate from signal to response as discussed by Welford [1971].

The subject was then seated in the chamber and verbal instructions as per Appendix A were given through the intercom

pertaining to what the presentation would be and how a correct response was initiated. Each subject was given twenty practice trials prior to each timed task.

Forty trials with one bit of information were presented and then forty trials with two bits of information were presented on the information processing device. The sequence of random numbers used for each subject are shown in Table II. A trial was defined as a correct response. Forty trials were selected in order to equate to the forty trials presented on the RATER. Previous research had been done on the RATER in the auto-paced configuration with 1.5 seconds per stimulus for a one minute test session (40 trials).

The subject was then asked to sit before the RATER which was also located in the same chamber. The subject was read the verbal instructions as per Appendix B. The subject was then given twenty practice trials prior to each timed trial on the RATER. Delay modes 0, 1, 2 and 3 were used in random order with the subject given a one minute rest period between each timed delay mode. A description of the subject's task on each delay condition follows.

1. Delay 0 = First Level of Integration = $H^{(1)}$

The subject first viewed an amber "ready" light for three seconds, followed simultaneously by a green "test" light and the first symbol. It was displayed for an indefinite period of time until the correct response to that symbol was made. It would then dim momentarily indicating a correct response, and then the next symbol would automatically appear.

ONE BIT PROCEDURE SEQUENCE			TWO BIT PROCEDURE SEQUENCE		
Trial	Number		Trial	Number	
	Practice	Timed		Practice	Timed
1	2	3	1	2	2
2	2	2	2	4	3
3	3	2	3	3	1
4	3	2	4	1	4
5	2	3	5	4	1
6	3	3	6	3	2
7	3	2	7	2	4
8	2	3	8	1	3
9	2	2	9	4	1
10	2	2	10	2	4
11	3	3	11	4	3
12	3	3	12	3	2
13	3	3	13	2	3
14	2	2	14	1	4
15	3	3	15	1	1
16	3	2	16	3	4
17	2	3	17	3	2
18	2	2	18	2	3
19	3	2	19	4	1
20	2	3	20	1	4
21		3	21		2
22		3	22		4
23		2	23		3
24		3	24		1
25		2	25		2
26		2	26		4
27		2	27		4
28		3	28		2
29		2	29		1
30		3	30		3
31		3	31		2
32		2	32		3
33		3	33		1
34		3	34		3
35		2	35		2
36		2	36		1
37		2	37		3
38		2	38		4
39		3	39		1
40		3	40		2

TABLE II: One Bit and Two Bit Number Sequence

If an incorrect response were made, the symbol maintained its original intensity indicating an incorrect response. This sequence was maintained until forty correct responses were completed.

2. Delay 1 = Second Level of Integration = $H^{(2)}$

Delay 1 was similar to Delay 0 except that the first symbol was present for only one and one-half seconds, and then the next symbol appeared which the subject was instructed to respond to. In other words, in delay mode 1, the subject responded one back from the one that was currently displayed. This sequence was maintained for forty correct responses.

3. Delay 2 = Third Level of Integration = $H^{(3)}$

Delay 2 was similar to Delay 1 except that the subject first viewed two symbols for fixed periods of one and one-half seconds each and no response was to be made until the third symbol appeared. Then the subject was to respond to the first symbol presented. This sequence was maintained for forty correct responses.

4. Delay 3 = Fourth Level of Integration = $H^{(4)}$

Delay 3 was similar to Delay 1 and 2 except that the subject viewed three symbols for fixed periods of one and one-half seconds each. When the fourth symbol appeared, subject was to respond to the first one displayed. This sequence was maintained for forty correct responses.

The instructions contained in Appendix A and Appendix B were read to each subject so that the same information was received by each subject.

Since correct trials were set, time was a variable and was obtained with a synchrous electric clock. The time from ready light to test light was three seconds and then each delay mode added on one and one-half seconds. Thus three seconds were subtracted from delay mode 1, six seconds subtracted from delay 2, and seven and one-half seconds subtracted from delay mode 3.

III. RESULTS

The results indicated no meaningful difference between the step-wise regression equation predictions for the different processing rate methods due to the high correlation between the variables as shown in Table III. Each correlation is significant at the .01 level. This result was consistent in all delay modes.

CORRELATION MATRIX

		S	1	2
		X(3)	X(4)	X(5)
S	X(3)	1.00	0.98	0.99
1	X(4)	0.98	1.00	1.00
2	X(5)	0.99	1.00	1.00

TABLE III: Correlation Analysis between the Slope, One Bit and Two Bit Information Processing Methods

The following regression equations were computed from the data for the specified delay levels for the particular processing rate method specified.

RT(D-0) = 57.671 - 2.975 R(S)

RT(D-0) = 72.610 - 14.583 R(1)

RT(D-0) = 67.456 - 8.431 R(2)

RT(D-1) = 70.100 - 3.662 R(S)

RT(D-1) = 86.161 - 17.044 R(1)

RT(D-1) = 80.919 - 10.058 R(2)

RT(D-2) = 117.796 - 6.414 R(S)

RT(D-2) = 147.406 - 30.429 R(1)

RT(D-2) = 137.370 - 17.780 R(2)

RT(D-3) = 151.115 - 7.168 R(S)

RT(D-3) = 179.574 - 32.199 R(1)

RT(D-3) = 170.293 - 19.165 R(2)

Each of the independent variables enter the regression equation at the .1 level or better.

The results again indicated no meaningful difference from the actual performance times as shown in Table IV in the methods for computing the information processing rates at delay 0. Each correlation is significant at the .01 level.

CORRELATION MATRIX

	Slope X(1)	1 Bit X(2)	2 Bit X(3)	Actual X(4)
S X(1)	1.00	0.99	1.00	0.73
1 X(2)	0.99	1.00	1.00	0.69
2 X(3)	1.00	1.00	1.00	0.70
Actual X(4)	0.73	0.69	0.70	1.00

TABLE IV: Correlation Analysis between the Slope, One and Two Bit Information Processing Methods with the Actual Times at Delay 0

The amount of information contained at delay 1, 2 and 3 resulted from the product of the mean of the different rate methods and the respective delay mean reaction times as shown in Table V. Eighty (80) bits of information were computed at

delay 0 as determined from the simple information processing techniques discussed in paragraph C of the problem section.

These results from the Two Bit method supported the previous findings of Van Gigch who initially approached this problem.

	Slope Method		One Bit Method		Two Bit Method		Van Gigch Method	
	Bits	Weight	Bits	Weight	Bits	Weight	Bits	Weight
D-0	80.000	1.000	80.000	1.000	80.000	1.000	80.000	1.000
D-1	320.387	4.005	108.892	1.361	162.339	2.029	160.000	2.000
D-2	523.572	6.545	177.949	2.224	265.292	3.316	240.000	3.000
D-3	731.944	9.149	248.770	3.110	370.874	4.636	320.000	4.000

TABLE V: Total Bits and Weighting Factors at Each Delay Level

IV. DISCUSSION

The results indicated with each method that as the mental task became more complex, then more information was processed on the RATER. The amount of information contained at the different levels was positively correlated with the values proposed by Van Gigch. The Two Bit method also closely supported the previous quantitative estimates proposed by Van Gigch.

Crossman [1964] stated that the range of information processing rates varied from as low as two to as high as fifty bits per second with a typical value of five bits per second. Hick [1952] defined information measurement when applied to a choice RT experiment as the amount of information in the choice divided by the RT and derived a constant of five bits per second. The experimental results ranged from a high mean value of 7.541 bits per second using the slope method to a low mean value of 2.563 bits per second using the one bit method. Hick's method, however, did not give any consideration to the cognitive processes involved and actually reduced the processing rate as more cognitive activities were required for the task.

Mowbray and Rhoades [1959] showed that after considerable practice for a period of five months, the choice RT difference between two and four choice times disappeared. This result would indicate a processing rate which was undefined and therefore meaningless. The experimentor felt that this result would not bias present experiment as only twenty practice trials were

given to achieve the necessary learned state prior to each actual timed trial.

The results also confirmed the results of Gagne and Fleishman's [1959] statement that correlations were high between RT made to different stimuli and with different responses.

Sheridan and Ferrel [1974] concluded that if the amount of information in a particular complex task can be determined, then this knowledge can be used in the equipment design in order that the operator will not become overloaded during the peak performance of that task. Krulee [1954] concurred and advised that the complex task be designed in order that operators process only that information which was actually relevant to the function performed. He recommended matching information requirements of the complex task to the information processing rate capabilities of the operator.

Further study is recommended in the following areas:

1. obtain an independent informational processing device that contains three or more choice alternatives in order to obtain a more reliable information processing rate

2. determine if the information processing rate is correlated with the intelligence quotient (I.Q.)

3. determine the weighting coefficients in a more operational environment such as a multi-task setting utilizing the RATER as the primary task.

APPENDIX A

INITIAL INSTRUCTIONS TO THE SUBJECTS (INFORMATION RATE DEVICE)

If at any time you want to talk with me, just speak into the intercom without pushing any buttons. Now we will check to insure if both intercoms are working properly. Do you hear me clearly at this time?

Sit up straight in your chair and place both hands atop the metal box in front of you with your palms resting on the buttons labeled two and three. When you see a number two or three displayed in the viewing window of the device in back, make the correct response as quickly as possible by pressing the corresponding button. You will have twenty practice trials before you respond for time. Do you have any questions?

Now that you have mastered the one bit response, we will now do the two bit response. Now in addition to your index fingers on the two and three buttons, rest your middle finger lightly on the one and four buttons, still resting the palm of your hand on the metal box. You will be given twenty practice trials in this position before you are timed. Do you have any questions?

APPENDIX B

INSTRUCTIONS TO THE SUBJECTS (RATER)

RATER is a test of your psychomotor skill. Four different symbols (plus sign, circle, triangle, diamond) will appear in a continuous random series in the viewing window. Each of the four response buttons below the viewing window corresponds to one of the four symbols. Your task is to respond to each symbol as it appears by pressing the corresponding correct button.

When you press the correct button for the particular symbol, the symbol will dim and upon releasing the button, another symbol will immediately appear. If you press an incorrect button, the symbol will not change but an error will be recorded. Continue trying to make the correct response until you obtain the dimming indication and the next symbol appears.

Try to be as fast, but as accurate as you can. Press only one button at a time. If you press more than one button simultaneously, an error will be recorded automatically. You will be given twenty practice trials in which to learn the correct button for each symbol.

Remember that the sequence of the symbols is completely random. Runs of the same symbol may occur. Do not try to anticipate which symbol will appear next.

Place the thumb and forefinger of each hand on the response buttons. Maintain this position throughout each trial. We will begin with mode 0 (1, 2 or 3).

(If delay 0 selected):

Watch for the ready light. A trial begins three seconds later when the test light comes on. Begin responding when the first symbol appears and continue to respond until the test light goes off. You will be given twenty practice trials in this position before you are timed. Do you have any questions?

(If delay 1, 2 or 3 selected):

In the delay mode, your task is to note the symbols as they are presented but to delay your response until one or more symbols have intervened. You will be told how long to delay your response. For example, with one-symbol delay in the self-pace mode, a symbol will appear which you should note and remember. When the next symbol appears, your response should be the normal correct response to the previous symbol, no longer present. At the same time, note the symbol present since it will determine the correct response for the next interval. In other words, you are responding in a continuous sequence except that you are delaying, or shifting, your sequence of responses by one symbol. The same principle applies for delays of two, three, and four symbols. To start responding in the delay mode, you must view one or more symbols prior to your first response. RATER presents the required number of symbols and then holds the following symbol until you make your first correct delay response.

(If delay 1 selected):

We will now do delay 1. You will respond to the symbol that was on just before the one that is currently displayed,

in this case the first symbol will appear and be on for 1-1/2 seconds and will be followed by the second symbol which will be on for an indefinite length of time until you respond correctly to the first one, then the third symbol will appear, and to that you must respond correctly to the second one that was presented, and so on so that you are always responding one back from the one that is currently displayed. You will be given twenty practice trials in this position before you are timed. Do you have any questions?

(If delay 2 selected):

In the next set of trials your task will be to respond to the symbol that was on two back from the one that is currently displayed. This is called delay 2. What you will see this time is the first symbol; it will be displayed for 1-1/2 seconds followed by the second symbol for 1-1/2 seconds and then the third symbol will appear. When the third symbol is displayed you will respond to the first one that was displayed, and when the fourth one comes on, you will respond to the second symbol that was displayed so that you are always responding two back from the one that is currently on. I want to remind you that you are to respond as quickly as possible to the correct answer. You will be given twenty practice trials in this position before you are timed. Do you have any questions on this set of trials?

(If delay 3 selected):

On this set of trials you are to respond to the third one back from the one that is displayed now. This is called delay 3.

In this case the first symbol will be displayed for 1-1/2 seconds followed by the second symbol for 1-1/2 seconds, and then the third symbol for 1-1/2 seconds, and then the fourth one will be displayed for an indefinite period of time until you respond correctly to the first one. When the fifth symbol appears, you are to respond to the second symbol that was on, and so on so that you are always responding three back from the one that is currently displayed. You will be given twenty practice trials in this position before you are timed. Do you have any questions on this procedure?

APPENDIX C

DATA

	RT(1)	RT(2)	R(S)	R(1)	R(2)	RT(D-0)	RT(D-1)	RT(D-2)	RT(D-3)	AGE
1	14.271	18.976	8.501	2.803	4.216	32.187	43.625	63.157	90.231	29
2	18.348	25.663	5.468	2.180	3.117	43.619	60.961	85.612	110.479	31
3	16.183	21.873	7.030	2.472	3.657	34.619	24.678	72.191	97.499	28
4	15.316	20.181	8.222	2.612	3.964	40.165	46.836	75.892	92.925	28
5	13.178	17.471	9.317	3.035	4.579	28.164	34.665	54.683	82.432	25
6	12.916	16.978	9.847	3.097	4.712	26.175	32.115	51.486	79.161	26
7	17.262	23.648	6.264	2.317	3.383	33.816	42.261	65.432	104.561	30
8	16.518	22.519	6.666	2.422	3.553	38.191	49.662	74.346	114.431	26
9	13.491	17.794	9.296	2.965	4.496	29.146	37.312	56.491	85.532	26
10	18.912	26.179	5.504	2.115	3.056	41.619	50.602	84.191	112.774	30
11	18.162	24.636	6.178	2.202	3.247	38.966	49.918	79.132	103.795	35
12	14.364	18.819	8.979	2.785	4.251	31.628	40.158	61.899	88.809	24
13	16.261	21.591	7.505	2.460	3.705	42.819	36.317	72.288	98.480	28
14	16.279	22.178	6.781	2.457	3.607	34.968	38.269	73.165	99.189	27
15	15.898	21.196	7.550	2.516	3.774	32.512	49.911	71.486	95.925	30
16	12.837	16.848	9.972	3.116	4.748	31.489	41.133	58.171	81.353	31
17	17.633	23.321	7.032	2.268	3.430	42.176	41.128	84.160	113.418	30
18	15.462	20.391	8.115	2.587	3.923	29.739	39.354	59.361	81.353	32
19	15.468	20.516	7.924	2.586	3.899	39.891	51.443	67.132	98.469	32
20	16.060	21.125	7.897	2.491	3.787	35.913	46.899	75.137	107.592	31

RT(1) = total reaction time for forty one bit responses

RT(2) = total reaction time for forty two bit responses

R(S) = slope method information processing rate

R(1) = one bit method information processing rate

R(2) = two bit method information processing rate

RT(D-0) = total reaction time at delay 0

RT(D-1) = total reaction time at delay 1

RT(D-2) = total reaction time at delay 2

RT(D-3) = total reaction time at delay 3

Age = age of subject

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162278